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EVALUATION OF LOW-EMISSION WOOD STOVES

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Introduction

Air pollution problems related to wood stoves and fireplaces have been increasing dramatically since the mid-1970's when the "oil crisis" stimulated a return to wood heating. (The current national contribution of wood energy is comparable to the nuclear energy contribution.) Mountain and resort communities have the additional burden of wood burning in fireplaces for aesthetics. In addition, the proposed emphasis by the U. S. Environmental Protection Agency (EPA) on only the smaller size particles of the total particulate matter in the air makes the wood smoke contribution even larger since virtually all of the wood smoke particulate matter is in this smaller size range. The number of regions in California and the nation which do not conform with national air quality standards due in part to wood smoke is large and growing.

This is both an economic threat and a health hazard. Economic development in non-attainment areas is restricted and mountain resort communities can suffer a loss of business if the views are marred by poor visibility. Components of wood smoke which are health hazards include carbon monoxide (C O), polycyclic-aromatic hydrocarbons or PAHs (some of which are linked to cancer), simpler hydrocarbons (HC), particulate matter (PM), and oxides of nitrogen (NOx).

Considerable previous research has been conducted on wood stove and fireplace emissions.[1,2,3,4,5] However, this research project has pushed into a number of areas which have been neglected in previous research. The unique aspects of this project include the following:

1) Many of the emissions have been measured not just during steady burning conditions but also over the initial light-up or kindling phase, and over the final charcoal phase. This adds considerably to the realism of the results.

2) This project has included more realistic fuels than many other projects. Both seasoned oak logs and green oak logs were used as well as the standard test fuel -- dimensional Douglas fir lumber. The results show that fuel can have a significant impact on emissions, but not always in the expected direction.

3) This project included tests on an extremely clean-burning wood-pellet-burning stove. Although pellet burners have been tested previously for emissions of particulate matter and carbon monoxide, this project included measurements of many other emittants, including nitrogen oxides, hydrocarbons generally, benzene, and elemental carbon, among others. The results indicate that not all emittants are decreased in such generally clean-burning systems.

4) Relatively little previous research has been done on fireplaces and open-door stoves. This project included an open-door wood burner in order to provide data on this most prevalent type of wood heater.

5) Creosote accumulation in the flue was measured for every test by weighing the flue before and after.

6) Parameters not included in many previous projects included benzene, elemental carbon, ammonia and cyanide.

7) This project included simultaneous use of two particulate measuring methods -- Oregon Method 7[6] and the ASTM (American Society for Testing and Materials) dilution tunnel method[7]) -- and two energy efficiency measuring methods -- Oregon indirect flue loss method[8] and a new direct flue loss method under development by the U.S. Department of Energy.[9] Comparison of the results indicates some inaccuracy in a test method that has been widely used.

Testing Scope and Methods

The range of appliances and fuels tested in this project are indicated in Table 1. The appliances consisted of a catalytic stove, two non-catalytic advanced technology stoves (Kent and Lopi), a conventional airtight stove, an open-door stove, and a wood pellet stove. This selection spans a full range of design types and actual performance.

The measured and calculated parameters are outlined in Table 2. Each test typically lasted 20 hours. The tests started with the stove at room temperature and included a kindling phase, from one to five main loads, and final charcoal phase. The test installation is illustrated in Figure 1.

Table 1: Appliance and Fuel Matrix

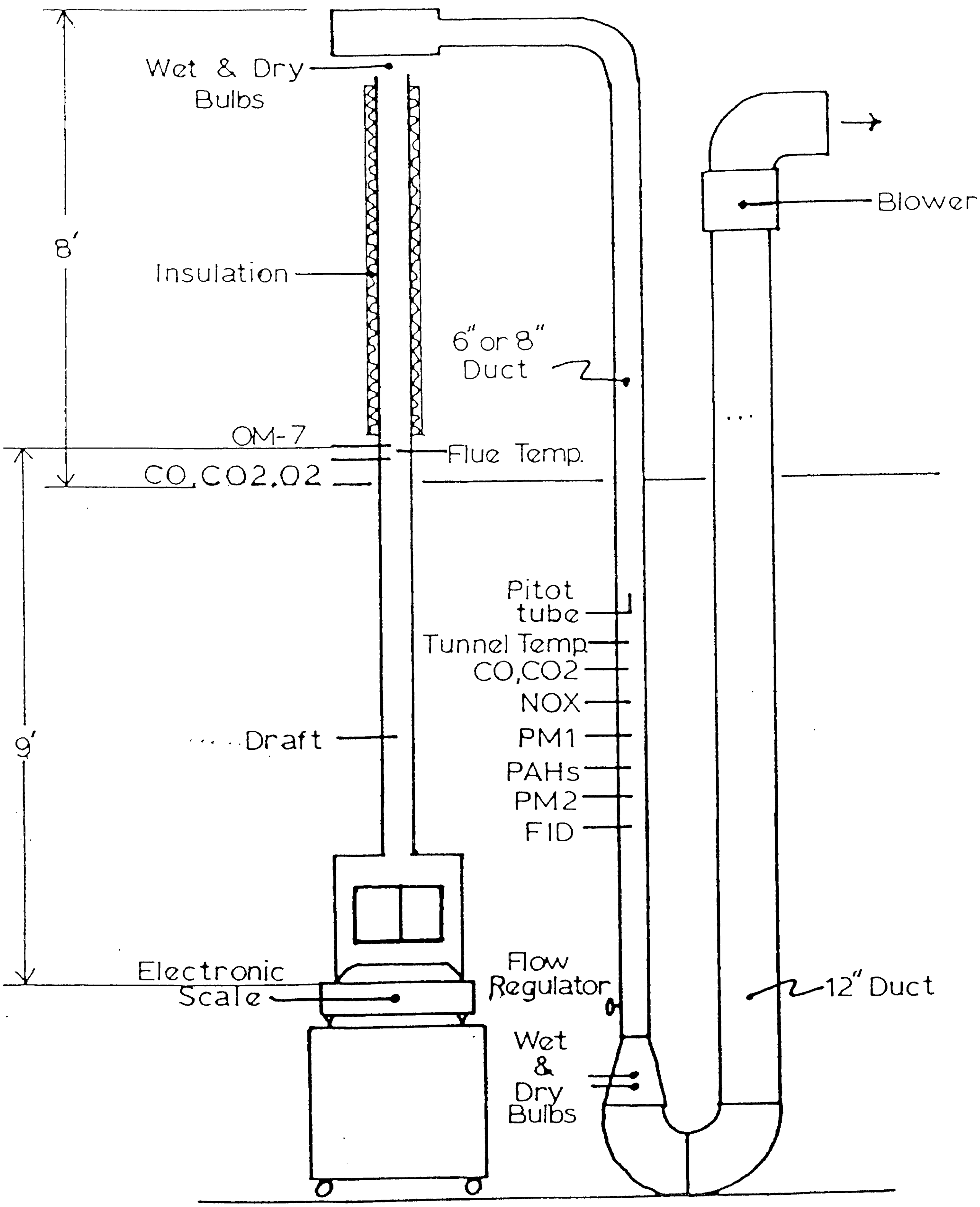
Table entries represent the number of cold-to-cold tests conducted over a range of burn rates.

	Oregon Fuel	Oak Logs 16-20% Moisture Content	Oak Logs 23-30% Moisture Content	Wood Pellets
Blaze King "King"	4	4	4	
Kent Tile Fire Mark II	4	2		
Conventional Closed Door		4	2	
Conventional Open Door		2		
Lopi A6 Insert	4			
Pellefier Pellet Burner				2

TABLE 2. MATRIX OF PRIMARY MEASUREMENTS AND RESULTS.

PARAMETER	SAMPLE SOURCE	METHOD	ENTIRE COLD TO COLD CYCLE	EACH PRIMARY PHASE (CHARCOAL, KINDLING, MAIN LOADS)	AVERAGE OF ALL PRIMARY PHASES	EACH MAIN LOAD
COMBUSTION EFF		DIRECT LOSS	X			X
COMBUSTION EFF		OREGON				X
HEAT TRANS EFF		DIRECT LOSS	X			X
HEAT TRANS EFF		OREGON				X
OVERALL EFF		DIRECT LOSS	X			X
OVERALL EFF		OREGON				X
NOX	TUNNEL	CHEMILUM.	X	X	X	X
HC	TUNNEL	FID	X	X	X	X
CO	TUNNEL	NDIR	X	X	X	X
CREOSOTE	FLUE	GRAVIMETRIC	X			
COMBUSTIBLES	TUNNEL	CO+HC+PM		X	X	X
PM	TUNNEL	FILTER		X	X	X
PM	FLUE	OM-7				X
PAH'S	TUNNEL	LIQ. CHROM.			X	
BENZENE	TUNNEL	GC			X	
ELEMENTAL CARBON	TUNNEL	SOLVENT EXTR.			X	
VOLATILE HC	TUNNEL	GC			(1)	
NH3 AND CYANIDE	TUNNEL	WET CHEMISTRY			(1)	
BURN RATE		SCALE		X	X	X
FLUE GAS FLOW		TRACER		X	X	X
FLUE GAS TEMP		THERMOCOUPLES		X	X	X
POWER OUTPUT		DIRECT LOSS				X
POWER OUTPUT		OREGON				X

1. DETERMINED OVER SELECTED INSTEAD OF ALL TESTS.



TEST INSTALLATION

Results and Conclusions

The observed emission factors (dry basis) are given in Table 3.

Table 3: Ranges for Emissions

	Minimum (g/kg)	Mean (g/kg)	Maximum (g/kg)	Phase
Particulate Matter (PM)	.10	.88	61	Main loads
Carbon Monoxide (CO)	1.6	86	307	Main loads
Hydrocarbons (HC)	.23	14	47	Main loads
Polycylic-aromatic Hydrocarbons (PAH)	.004	.24	.55	Cold-to-cold
Nitrogen Oxide (NOx)	.22	.51	1.1	Main loads
Benzene	< .02	.70	2.2	Cold-to-cold
Elemental Carbon	< .08	.67	2.2	Cold-to-cold
Cyanide			< .0005	Main loads
Ammonia	.001	.026	.10	Main loads
Creosote	.2	2	10	Cold-to-cold

Appliance effects were strong. All products of incomplete combustion (PM, CO, HC, benzene, PAH, elemental carbon, and creosote) were lowest for the pellet burner, next lowest for the catalytic stove, and highest for the conventional airtight stove.

Fuel effects were largest for NOx and elemental carbon. Both these emittants were highest for the green oak and lowest for the Douglas fir.

Some emittants were measured during each of the major burn phases -- kindling, main load, and charcoal. Generally, the contribution to total emissions from the kindling and charcoal phases was no larger than from the main loads. However, the one prominent exception was PM for the catalytic stove, wherein the kindling phase contributed up to five times more PM to the atmosphere than a main load. This is of possible significance since current wood stove emissions regulations are based on main load performance only, although the complexity of including the kindling phase in a test protocol may dictate against changing current protocols.

Burn rate had a dramatic effect on emissions. The catalytic stove's advantage in combustion efficiency was very pronounced at medium to low burn rates -- the burn rates most utilized in the field. However, at high burn rates the non-catalytic stoves performed nearly as well as the catalytic. The pellet burner's combustion efficiency remained high at all of its burn rates, but the burn rate range was relatively narrow.

Overall energy efficiencies generally correlated with clean combustion; the cleaner stoves generally consumed less fuel to produce the same amount of useful heat. However, an exception to this is the pellet burner. Although it had the highest combustion efficiency, its overall efficiency was not the highest. The system uses a relatively large amount of combustion air. This tends to carry more heat up the flue.

Creosote correlates well with particulate matter. Thus cresote will be reduced with stoves certified to have low PM emissions. By this mechanism regulation of emissions can improve safety of heating with wood.

The two most common test methods for wood stove PM correlate with each other but do not give the same result. Oregon Method 7 always yields a higher emission rate because it includes material which would be in vapor phase in the atmosphere. The dilution tunnel is a better measure of PM in the atmosphere but does not catch all of the organics that OM7 does.

The Oregon indirect stack loss energy efficiency test method appears to underestimate the efficiency of high efficiency stoves by between five and ten percentage points.

Recommendations

There is a large range of actions that can be taken to improve air quality in a geographical area with a significant amount of wood smoke. These range from prohibiting burning of wood to voluntary no-burn times. This project addressed the specific areas of appliance design, operation, and fuel. In these areas, the following recommendations follow from this project:

1. Appliance design can have a very large effect on organic emissions. Requiring catalytic and other equally effective designs is likely to reduce these emissions by a substantial amount -- on the order of a factor of 10.

2. Recommending use of seasoned instead of green fuels will not substantially reduce most emissions from stoves. (The two exceptions are NOx and elemental carbon.) However, seasoned wood can reduce most emissions from open stoves and fireplaces by roughly a factor of two.

3. Catalytic and other low emitting chunk-wood stoves should be used according to the manufacturer's instructions; otherwise emissions may not be reduced. When operated with bypass dampers open or doors open, there is little benefit. For catalytic stoves steady burning at medium to low burn rate will usually result in lower emissions than burning the same amount of wood in shorter but higher-burn-rate periods. Each kindling phase from a cold start can contribute as much to emissions as an entire twenty-four hour day of steady use with the combustor engaged.

4) NOx emissions are not closely related to the combustion technology of a wood burner. Thus regulations which encourage particular wood burning technologies will not have much impact on NOx emissions.

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